EUV Irradiance Variations Measured With the SOHO Coronal Diagnostic Spectrometer

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Abstract

The Coronal Diagnostic Spectrometer aboard the Solar and Heliospheric Observatory observes the solar EUV spectrum in two bands between 308-379 Å and 513-633 Å. The full Sun irradiance can be measured by rastering the instrument over the solar disk. Measurements of the solar irradiance have been made starting 25 March 1997 and continuing to the present, ranging from very quiet to very active Sun. These measurements are the only current EUV spectral irradiance measurements taken on a regular basis. As well as irradiance values, the most recent observations also provide moderate resolution solar images to help quantify the important sources of the irradiance variability. The dependence of individual spectral lines on the solar cycle is presented, spanning the temperature range from 3 X 10^4 K to 2.7 X 10^6 K. The important spectral lines of He II and Si XI at 304 Å are observed in second order and separated. The high spectral resolution of these measurements, combined with the coverage of a significant proportion of the solar cycle, provide a unique dataset for understanding solar variability in the EUV. In addition, these data are important input for interpreting data from broadband and lower resolution irradiance monitors, such as the SOHO SEM and TIMED.

Calibration

The calibration used for the CDS NIS measurements are based on two sounding rocket underflights. Coordinated observations of the solar irradiance were made on 15 May 1997, together with the EUV Grating Spectrometer (EGS) instrument aboard a NASA/LASP sounding rocket. The highly precise calibration of the EGS instrument (8-10 %), combined with the coincident CDS observations of the irradiance allows a calibration curve to be derived for the CDS instrument except for parts of the NIS band.

Measurements of the solar radiance of an active region target with another sounding rocket underflight extended the calibration to the remainder of the NIS-1 wavelength band. The Solar Extreme-ultraviolet Research Telescope and Spectrograph was launched on 18 November 1997. During the flight, both the SERTS and CDS instruments were co-pointed at the same target. By combining the SERTS measurements with the EGS measurements at 368 Å, a complete NIS-1 calibration curve could be derived.

Observations

The Normal Incidence Spectrometer (NIS) of the SOHO Coronal Diagnostic Spectrometer (CDS) observes spatially resolved spectra in two bands, NIS-1: 308-379 Å, and NIS-2: 513-633 Å . A special observing program allows the full-Sun irradiance to be measured by rastering over the entire Sun. A full scan takes approximately 13 hours, and is performed on a roughly monthly basis. Figure 1 shows representative full-Sun NIS spectra. The spectral resolution varies from 0.3 to 0.6 Å, allowing the separation of closely spaced lines.

Full disk irradiances have been measured with CDS starting on 25 March 1997, when the Sun was close to solar minimum ($F_{10.7}$ = 70). A total of 7 irradiance measurements were made up through the summer of 1998, during which time the level of solar activity increased substantially ($F_{10.7}$ = 104). The irradiances of a total of 154 separate spectral lines have been extracted from these data for each observation date, with corresponding emission temperatures ranging from 3 X 10^4 K (He I) to 2.7 X 10^6 K (Fe XVI). Figure 2 shows monochromatic images of the Sun in selected lines from the CDS irradiance data.

Figure 3 shows the measured irradiance from the Mg X line at 625 Å as a function of time. Also shown is the radio flux $F_{10.7}$ for comparison. There are still some issues to be worked out regarding the calibration of the post-recovery data. Therefore, we will only consider the pre-accident for the remainder of this report.

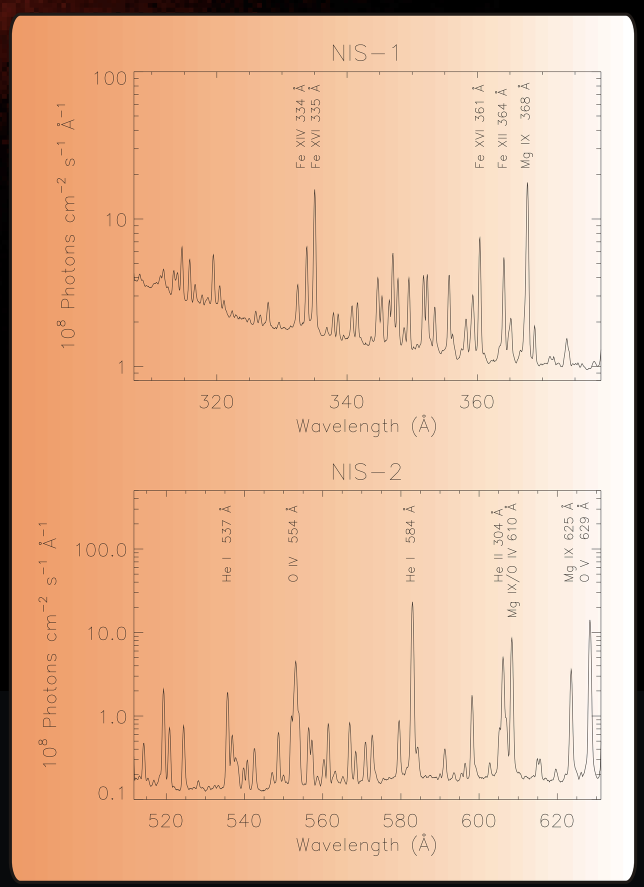

Figure 1:

Representative CDS full-Sun irradiance spectra in the two wavelength bands. A selection of prominent lines are identified. Irradiances from 154 separate spectral lines have been extracted. The apparent continuum component is actually due to off-band scattering in the spectrometer.

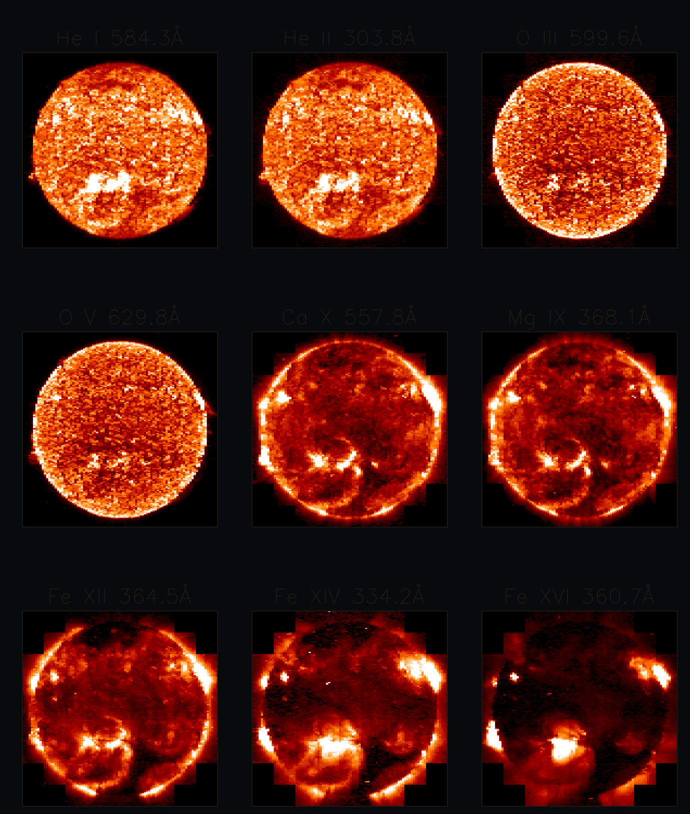

Figure 2:

Monochromatic images of a representative sample of spectral lines, ranging in formation temperature from 3 X 10^4 K to 2.7 X 10^6 K, taken on 23 April 1998.

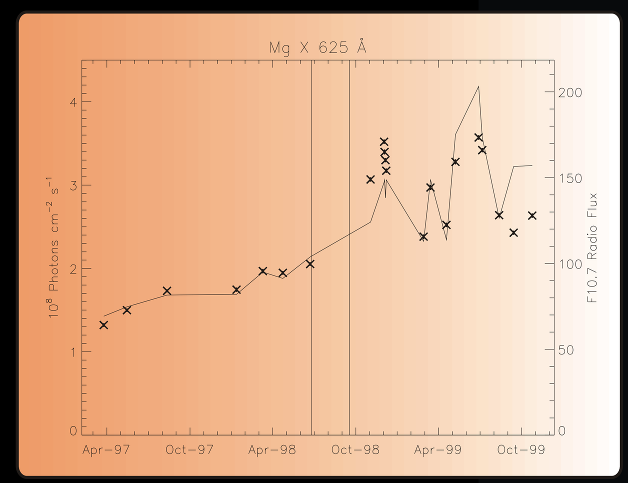

Figure 3:

Solar irradiance from the Mg X line at 625 Å (X symbols) as a function of time. Also shown is the $F_{10.7}$ radio flux (solid line) for comparison. The vertical dashed lines represent the temporary loss and subsequent recovery of SOHO pointing control.

Comparison With EUV Models

We compared our results against four standard models for the EUV irradiance: Hinteregger (Hinteregger et al., 1981); EUVAC (Richards et al., 1994); EUV97 (Tobiska and Eparvier, 1998); SOLAR2000 (Eparvier, private communication). The comparison with the SOLAR 2000 is shown in Figure 4.

The primary purpose of the above models is to predict the total integrated EUV flux. Figure 5 shows the total integrated flux in the two wavelength bands against the model predictions, as a function of time. The NIS-1 band is dominated by coronal lines, and the NIS-2 band is dominated by chromospheric and transition-region lines.

Of the four models, the EUVAC model matches best the temporal variation in both wavelength bands, although it's too low for NIS-1, and too high for NIS-2. It's also the closest to the measured irradiance in the NIS-2 band. In NIS-1, the closest match is the EUV97 model, but only for high levels of solar activity. For low solar activity, the Hinteregger model is slightly better.

The observations have also been compared with other instruments. Figure 6 shows a comparison of the second order He II/Si XI 304 Å to the Solar EUV Monitor (SEM) instrument on SOHO.

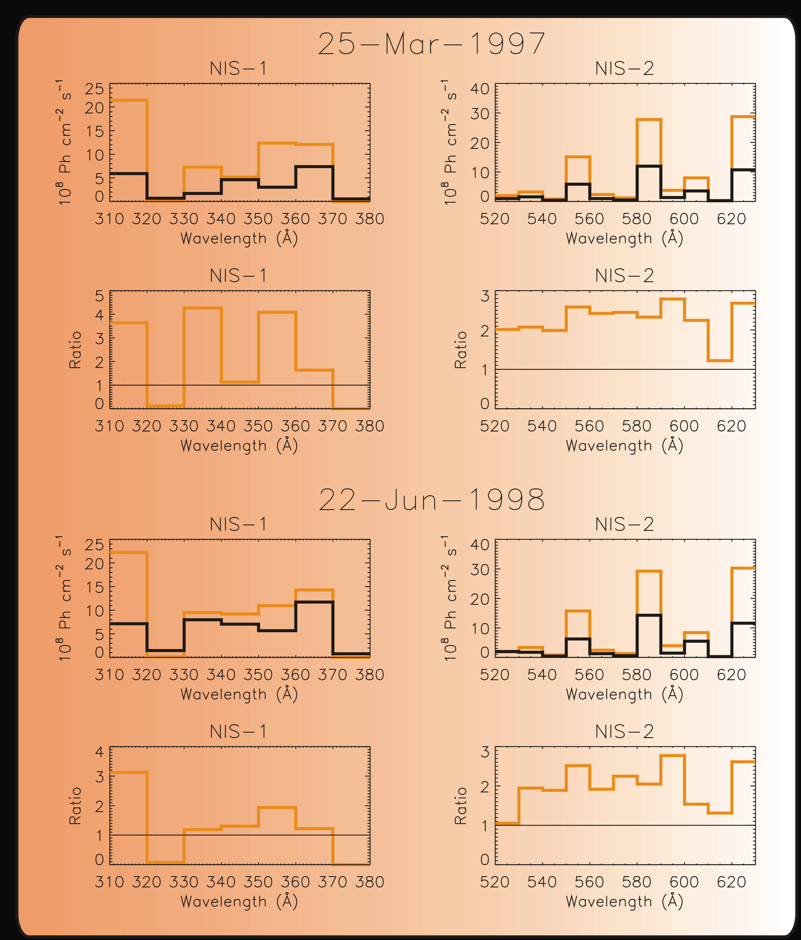

Figure 4:

Comparison of the Irradiance measured with CDS (black) against the SOLAR 2000 model (orange) For both low solar activity (25 March 1997) and high activity (22 June 1998). For each date, the upper panels show the irradiances in 10 Å bins, and the lower panels show the ratio of the model to the measurements. In general the model Tends to overestimate the quiet-Sun NIS-1 spectrum, but is more successful when solar activity is higher. The NIS-2 spectrum is in general overestimated-by about a factor of two for the stronger lines.

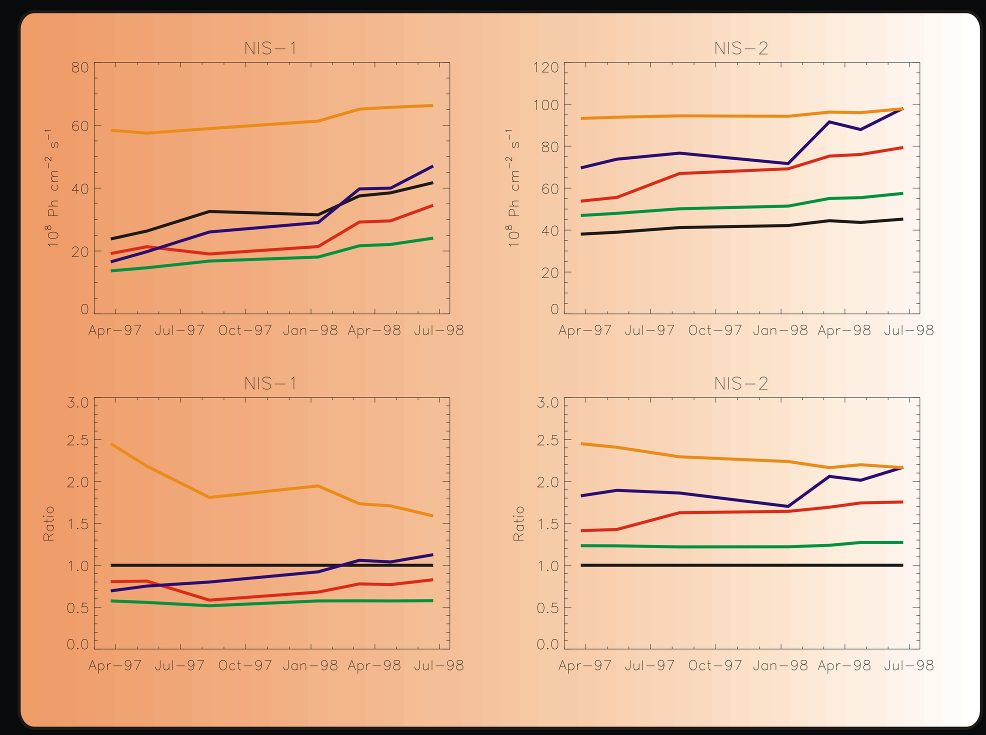

Figure 5:

Comparison of the total integrated irradiance in each wavelength band measured with CDS (black) against the Hinteregger (red), EUVAC (green), EUV97 (blue), and SOLAR2000 (orange) models. In the upper two panels are shown the total integrated irradiances in the two NIS wavelength bands. In the lower two panels are the ratios of the models to the measurements. NIS-1 is dominated by coronal lines, while NIS-2 is dominated by chromospheric and transition-region lines.

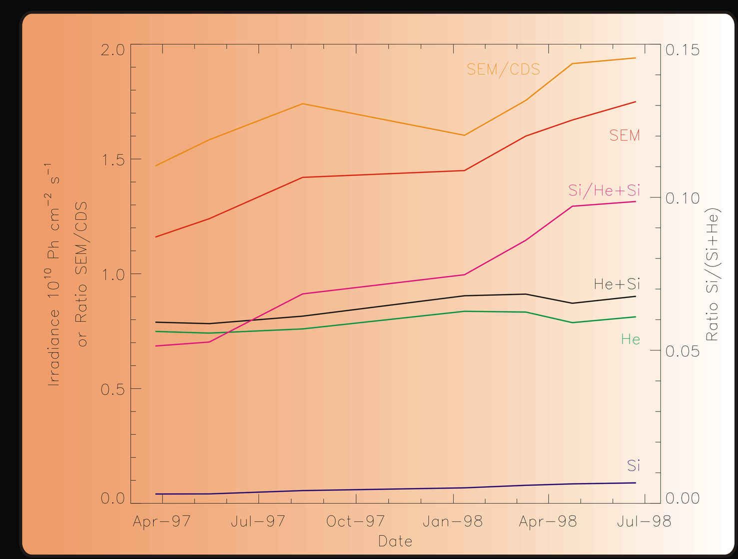

Figure 6:

Comparison of the CDS irradiance measurements in the two second-order lines of He II and Si XI at 304 Å (black) to the broadband measurements by the SEM instrument (red). The ratio of the SEM to the CDS measurements (orange) shows that these two lines contribute about half of the SEM signal. There's also a slow rise in the ratio, which may either be due to increased contribution from coronal lines in the SEM bandpass, or loss of sensitivity in CDS. The individual contributions of the He II (green) and Si XI (blue) components are shown, as well as the steadily rising ratio of Si XI component to the total (purple)

Conclusions

We have demonstrated that the CDS instrument can be used to measure the EUV irradiance in 154 separate spectral lines. Observations over a period of several years allow the characterization of the temporal behavior of spectral lines as a function of formation temperature. These data serve as a useful check on irradiance models based on proxy measurements such as the F_10.7 radio flux, and demonstrate that revisions are needed in the current models.

Future work will extend this analysis to the post-recovery data, after finalizing the calibration for this period.

Acknowledgments

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